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Road transport energy consumption in the G7 and BRICS: 1973-2010

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Abstract: Road transport will account for a large share of developing countries' future energy demand. This paper reviews the trends in road transport energy consumption in 12 countries (Group of 7 and BRICS) over the period 1973-2010. We report several stylised facts: road transport energy use and its share in total energy use have been rising; there were large differences in road transport energy use per capita across countries, resulting from differences in country size, resource endowments, fuel prices, and other factors; oil accounts for approximately 95% of road transport energy in the selected countries (except Brazil); oil will likely be the dominant road transport energy source in most countries for some years to come but not in the long run; and the use of alternative road transport energy sources is increasing.

Keywords: Road transport; Energy consumption; Historical

1 Introduction

Transport is a vital sector for any economy and nation. Road transport is one of the mostly widely used and popular means of transport and is also a key energy consumer. As incomes rise and urbanisation continues, demand for road transport is also increasing. Given this, it is important to document the characteristics and trends of long-term energy consumption for road transport and to compare the experiences of countries at different development levels. We do so in this paper.

Our focus is on the global experience and the country experiences of the members of the original Group of Seven (the United States (US), Canada, the UK, France, Germany, Italy, and Japan) and the five BRICS countries (Brazil, Russia, India, South Africa, and China). These countries are important; in 2010, their gross domestic product (GDP; purchasing power parity (PPP), 2005 constant prices), energy consumption, and road transport energy consumption accounted for 63.9%, 61.8%, and 62.1% of the world's totals respectively. Here "road transport" refers to road-based movement of people and freight in and between cities, whether private or public. There is a "derived demand" for energy use to provide transportation services. Our data consider only the energy consumed during transportation rather than energy consumed in the construction of transport infrastructure and equipment.

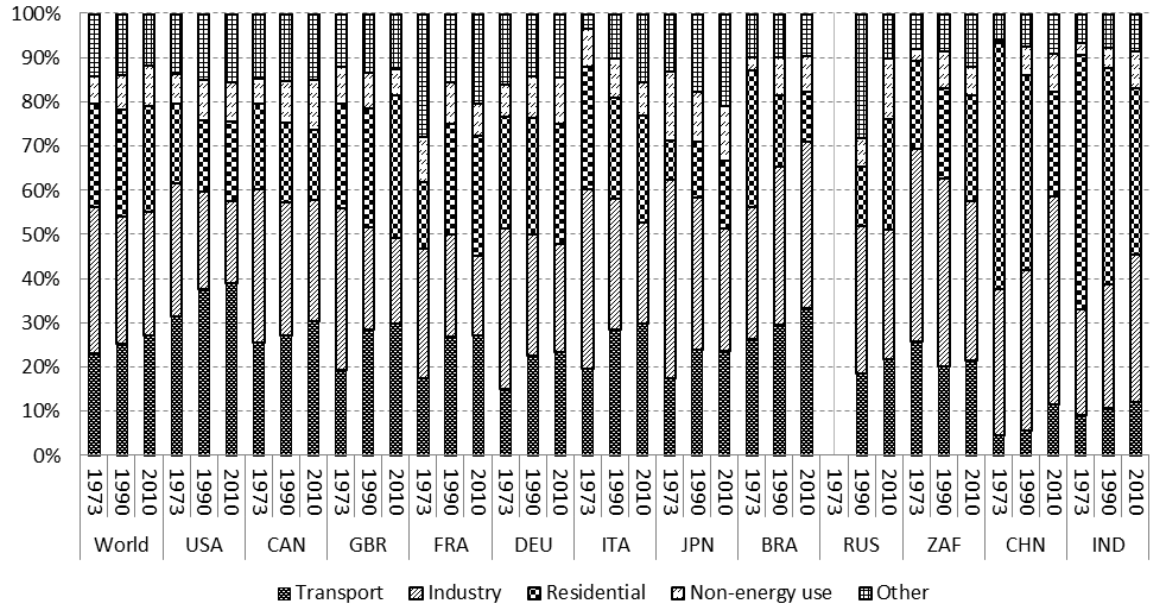
The data we use are mainly from the International Road Federation (IRF, 1960-2012), International Energy Agency (IEA, 2012), and U.S. Energy Information Administration (U.S. EIA, 2012). Energy consumption is calculated using the thermal equivalence method. Russian data are available from 1990. The data for Germany include both East and West Germany.

2 Energy use by the transport sector

In 2010, the global transport sector consumed 2.4 billion tonnes of energy in oil equivalent terms, which equalled 27.2% of global final energy consumption (up 4.1 percentage points since 1973). This makes transport the second-largest energy-consuming sector behind industry. According to IEA statistics, at the national level, transport energy consumption includes: road, railway, domestic water-borne, domestic air, and pipeline-based modal energy consumption. International aviation and marine transport are not included in national-level data. As seen in Figure 1, the transport share of final energy consumption increased over our period of analysis in all countries in our sample except South Africa. The transport sector accounts for a higher proportion of total final energy consumption in developed countries than developing countries.

In the developed countries in our sample, defined as the Group 7, two phenomena are observed. First, industrial energy consumption has levelled off as these countries have moved to more service-based economies and have achieved energy efficiency improvements. Second, increasing demand for transport (and more comfortable transport, for example by private vehicle) has seen the amount of energy used in transport increase, despite energy efficiency improvements in transport also. As a result of these two phenomena, the transport share of total final energy use has risen.

Figure 1 Structural variation in total final energy consumption



Note: World Bank country abbreviations used throughout. BRA = Brazil; CAN = Canada; CHN = China; DEU = Germany; FRA = France; GBR = United Kingdom; IND = India; ITA = Italy; JPN = Japan; RUS = Russia; USA = United States; ZAF = South Africa.

In 2010, the US's transport energy consumption reached 580 million tonnes of oil equivalent, accounting for 38.9% of final energy consumption (an increase of 7.4 percentage points from 1973). Canada's transport energy consumption was 60 million tonnes of oil equivalent, accounting for 30.4% of final energy consumption (an increase of 4.8 percentage points since 1973). Transport energy consumption has reached approximately 40 million tonnes of oil equivalent in each of France, Italy, and the UK, nearly 30% of their final energy consumption (an increase of approximately 10 percentage points since 1973). Germany and Japan's year-2010 transport energy consumption was 50 million and 80 million tonnes of oil equivalent, accounting for 23.7% and 23.4% of final energy consumption (increases of 8.4 and 6.3 percentage points since 1973). Transport, rather than industry, has become the largest energy-consuming sector in France, Italy, the UK, and the US.

In the developing countries in our sample, defined as the BRICS, industrial energy use has continued to increase, but transport energy consumption has in fact increased even more rapidly. In China and India, transport remains a relatively small, although growing, contributor to total energy consumption. By 2010 the transport share of final energy consumption increased to 11.5% in China (up from 4.5% in 1973) and 12.1% in India (up from 9.2%). Transport guzzled 170 and 60 million tonnes of oil equivalent in the two countries in 2010, respectively.

Transport-sector energy consumption in Brazil reached 70 million tonnes of oil equivalent in 2010. The transport sector's share of total final energy consumption in Brazil – at 26% in 1973 and 33% in 2010 – was higher than other developing countries. This is as a result of factors including Brazil's large land area, relatively sparse population, and relatively low residential energy consumption. South Africa is the only country to have had a declining share of transport in final energy over the period. The proportion of final energy use attributed to the transport sector in South Africa decreased from 1973 to 1990, followed by a slight increase from 1990 to 2010.

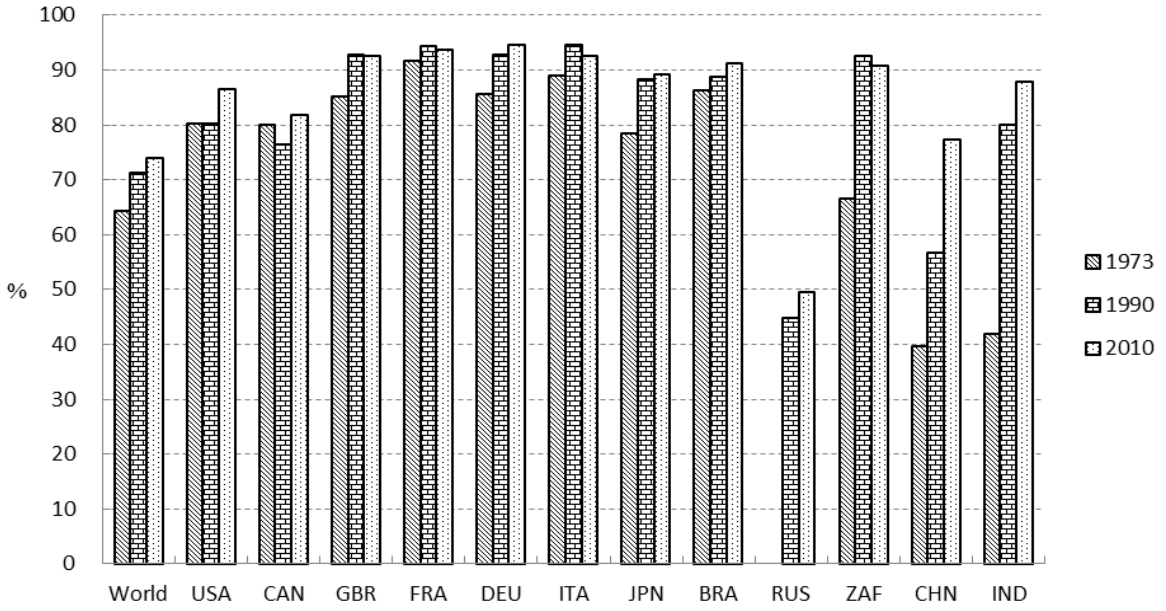
3. Road transport

3.1 Road transport energy consumption versus total transport energy consumption

Road transport usually makes up the majority of total transport energy consumption, a share that is typically increasing (Figure 2). From 1973 to 2010, global road transport energy consumption rose from 0.7 billion to 1.8 billion tonnes of oil equivalent, an average annual

growth rate of 2.6% per annum. Over the same period, global final energy consumption and GDP grew at average annual rates of 1.7% and 3.2% respectively.

Figure 2 Proportion of road transport energy consumption in total transport energy



In developed countries, the share of road transport in domestic transport energy use reached about 80% in 2010, having gradually increased over the last 40 years. Germany is the most road-dependent (94.7% of transport energy), followed by France at 93.8%. In both Italy and the UK, the proportions were 92.7%.

From 1973 to 2010, the road share of transport energy use in China, India, and South Africa grew significantly. China and India both doubled their shares (China: from 39.6% to 77.3%; India: from 42% to 88%). South Africa's road share of transport energy use increased from 66.7% to 90.8% over the period. The proportion of rail transport energy consumption in these three countries decreased as road vehicle use gradually overtook rail use. Russia had the

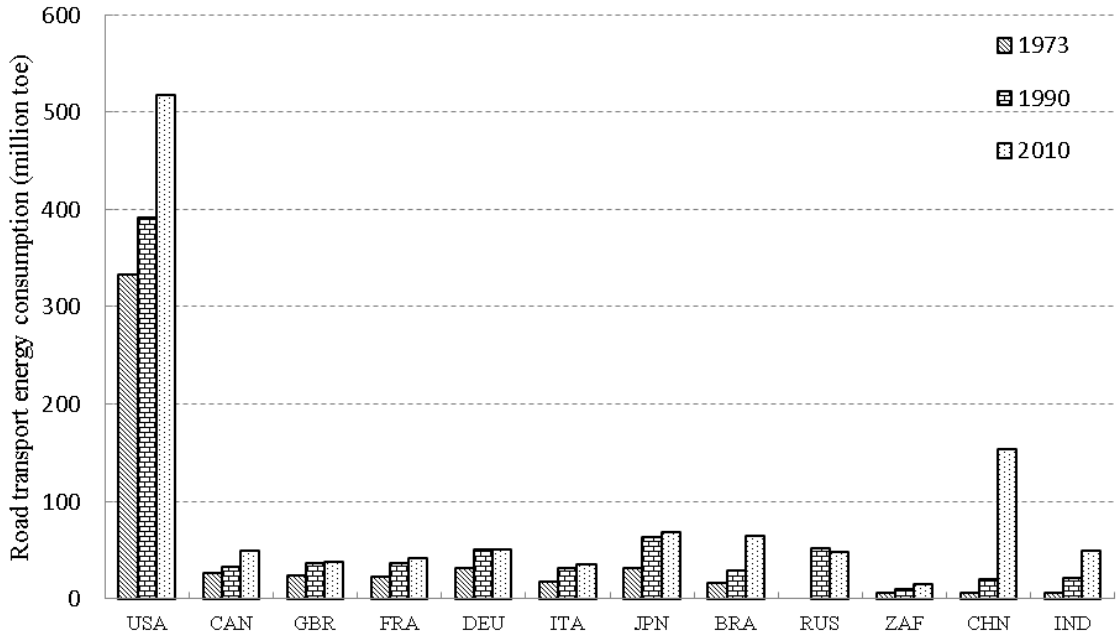
lowest proportion of road transport energy consumption (49.6%) in 2010, up from 44.9% in 1990. The reasons for this low share lie in Russia's cold climate (which dissuades some road-based travel), vast land area, and its widespread use of pipeline-based transport (with a transport energy consumption proportion of 36.6%).

3.2 National stories on road-transport energy use

Figure 3 shows that, since 1973, national road transport energy consumption of each country sampled has increased, but at different rates.

Owing to its large land area, large population, abundant resources, high income level, and profligate consumption habits, the US has a road transport energy consumption that is far higher than in other countries. In 2010, the total road transport energy consumption of the US was 520 million tonnes of oil equivalent, which was about 13.7 times that of the UK, 7.5 times that of Japan, and 3.4 times that of China. The US accounts for 28.8% of global road transport energy consumption; all the other countries in our sample combined account for 34.1%.

Figure 3 Total road transport energy consumption



Note: toe is "tonnes of oil equivalent".

Japan ranks first in terms of road transport energy consumption per unit land area, using 211 tonnes of oil equivalent/km^2 in 2010. The UK, Germany, and Italy also have relatively high values (171, 152, and 131 tonnes of oil equivalent/km^2, respectively). The (less densely-populated) US and Canada consume only 63.8 and 6.5 tonnes of oil equivalent/km^2 respectively.

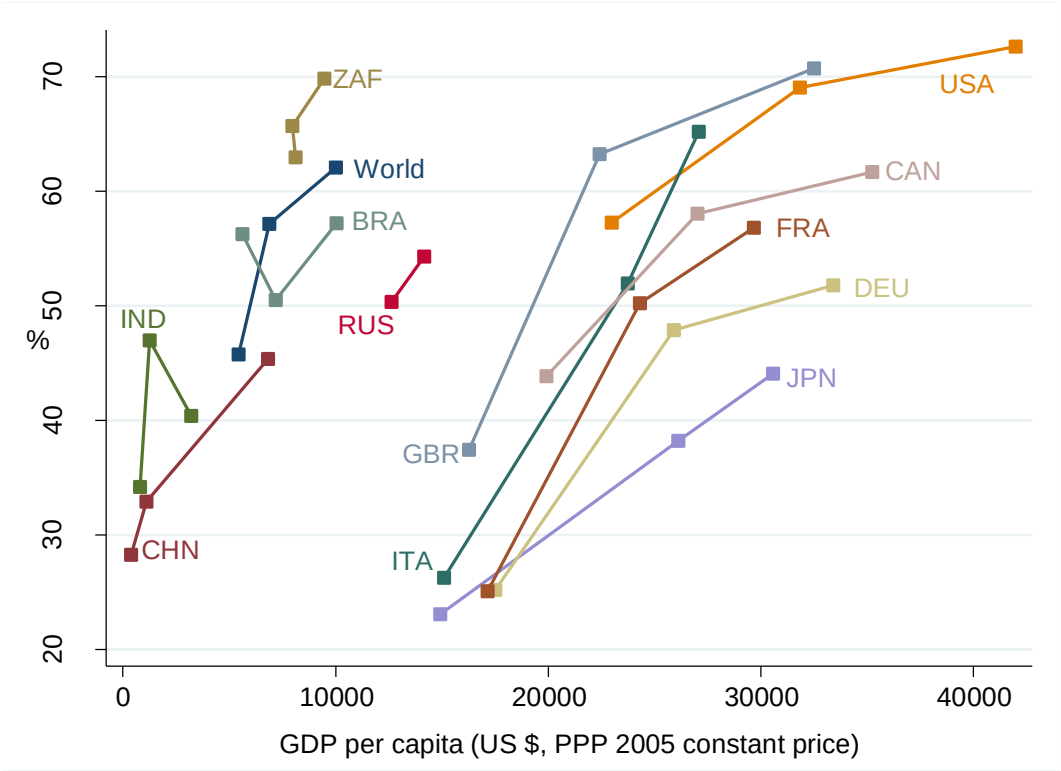
France, Germany, Italy, the UK, and Japan displayed generally similar road transport energy consumption trends due to their similarities in states of development and geographical conditions. Since 1973, the road transport energy consumption of each of these five countries has increased. From 1973 to 1990, their road transport energy average annual growth rates were about 3%. Since 1990, these average annual growth rates fell to less than 1%. Japan's total road transport energy consumption (69 million tonnes of oil equivalent) was higher due to its larger population.

China's rapid economic development has seen its road transport energy consumption grow from 6.5 million tonnes of oil equivalent in 1973 to 150 million tonnes of oil equivalent in 2010 (an annual average growth rate of 8.9%). Other developing countries such as India and Brazil also showed rapid growth in road transport energy use. From 1973 to 2010, road transport energy consumption in India increased from 5.7 million tonnes of oil equivalent to 48.8 million tonnes of oil equivalent, an average growth rate of 6.0% per annum. South Africa's use of energy in road transport increased from 6.4 million tonnes of oil equivalent to 12.0 million tonnes of oil equivalent, an average annual growth rate of 3.7%.

3.3 Road transport is gradually becoming the main oil consumer in all countries

The road transport share of total final oil consumption has increased, both globally and in our countries of focus (Figure 4). This share is particularly high in developed countries (except Japan), where more oil is consumed in road transport than in all other final-consuming sectors combined. Developing countries currently use a relatively large share of their (final-use) oil in their industrial sectors, but are most likely on track to a similar situation of road-transport sector dominance in national final oil demand. In the long run this situation may change, but historical trends are clearly towards a growing share of oil being used in road transport. The trend is partly a function of falling use of oil in some other sectors, such as electricity (Burke, 2010).

Figure 4 The proportion of road transport oil consumption in final oil consumption in 1973, 1990 and 2010



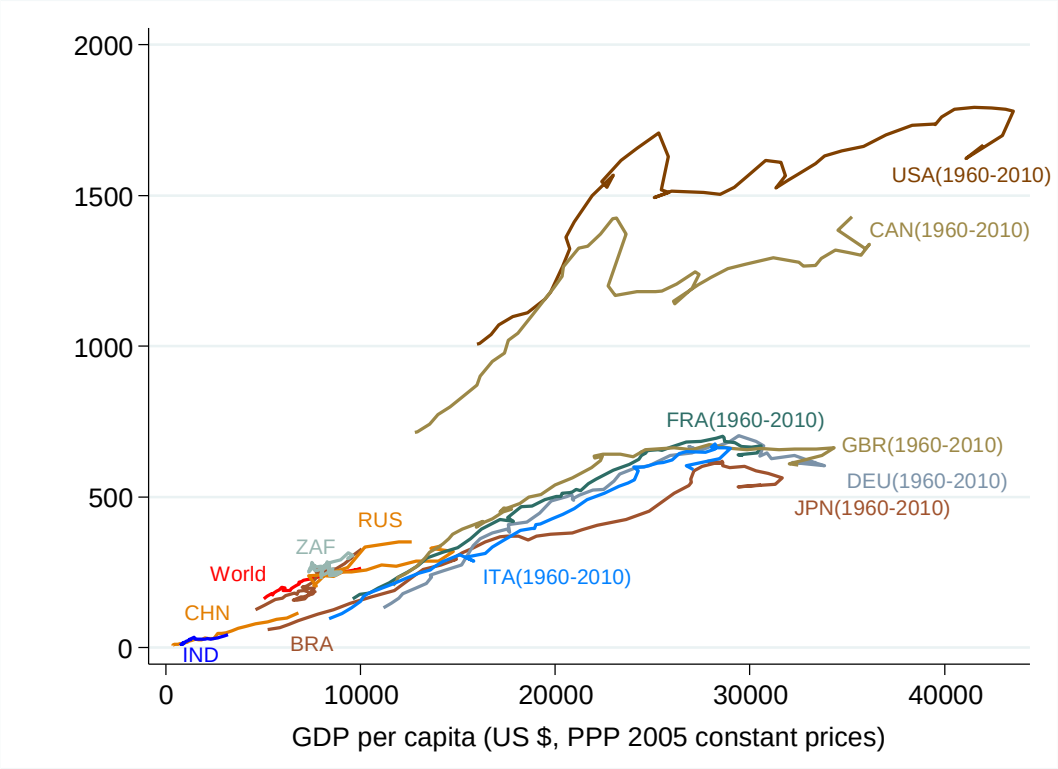
Note: Oil is also used in some energy transformation processes, such as the generation of electricity. This oil is not included in “final consumption”; it is instead part of the broader concept named “primary consumption”.

3.4 Per capita road transport energy consumption versus per capita GDP: A longitudinal perspective

Over time, per capita road transport energy consumption is significantly and positively correlated with per capita GDP (Figure 5). In developed economies, however, there has been some lessening of the extent to which per capita road transport energy consumption increases with per capita GDP as the road transport sector has matured. The GDP per capita level at which per capita road transport energy consumption has reached a local peak has differed across countries: this level was around $25,000 and $23,000 in the US and Canada (2005 constant prices, PPP, and similarly hereinafter), while in the EU countries and Japan it was about $30,000. In recent years, per capita road transport energy consumption has in some instances (e.g. US, Canada) begun to increase again. It is too early to conclude that these countries are near "peak energy use in the road transport sector". Figure 4 also shows that road transport energy use can show short-run declines, especially during recessions and/or times of high oil prices.

From 1973 to 2010, the per capita road transport energy consumption of China and India increased at average annual rates of 8% and 4% respectively. Due to the form of its economic transition, Russia firstly saw a decrease, and then rapid growth, in per capita GDP and per capita road transport energy consumption. The per capita GDP and per capita road transport energy consumption of South Africa did not show an increasing trend until 1990 (attributable to historical reasons related to the end of apartheid).

Figure 5 Per capita road transport energy consumption versus per capita GDP, 1971-2010



Note: GDP is from IEA (2012). kgoe is "kilogrammes of oil equivalent".

Table 1 lists the elasticity of per capita road transport energy consumption to per capita GDP for each country for three time periods from 1960 to 2010. The road transport energy: income elasticity of the developed countries exceeded 1.0 in the period before 1973 and in some instances exceeded 2.0. Rapid economic development of these countries was associated with even more rapid road transport growth. From 1973 to 1990, this elasticity reduced in all developed countries.

Table 1 Elasticity of per capita road transport energy consumption to per capita GDP (1960-2010)

	USA	CAN	GBR	FRA	DEU	ITA	JPN	BRA	RUS	ZAF	CHN	IND
1960-1973	1.2	1.2	2.2	1.7	2.5	2.0	1.6	-	-	-	-	-

1973-1990	0.0	0.0	1.3	1.1	1.2	1.3	1.0	0.8	-	-0.4	0.8	2.3
1990-2010	0.2	0.7	-0.1	0.1	-0.1	0.6	0.3	1.5	-0.3	0.6	1.0	0.5

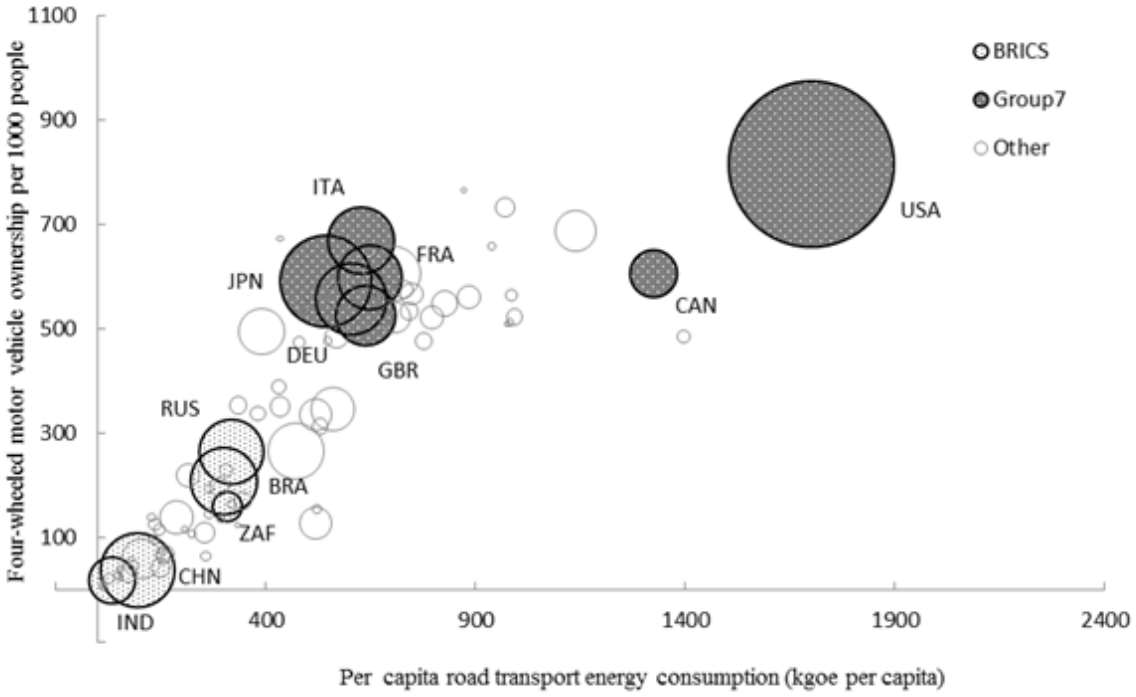
The road transport energy: income elasticities of the US and Canada were close to zero during 1973-1990, while those of the other countries were *c*. 1.0 i.e. economic growth was similar to the growth rate of road transport energy consumption. After 1990, owing to changes in the means by which economic growth was manifested, the growth rate of road transport energy use was lower than the economic growth rate in developed countries, and in some cases per capita road transport energy consumption was negative. In developing countries, the road transport energy: income elasticities of China and Brazil were below 1.0 before 1990; after 1990, as structural change drove robust growth of road transport, they exceeded 1.0.

3.5 Explanations of differences between countries

The per capita road transport energy consumptions of the US and Canada were about 1.5 tonnes of oil equivalent, vastly higher than those of the other countries. Per capita road transport energy consumption in the EU countries and Japan was about 0.6 tonnes of oil equivalent. Brazil, China, and India had per capita road transport energy consumptions of 0.3, 0.1, and 0.04 tonnes of oil equivalent, respectively. The sizeable differences between countries are largely driven by the stage of development; countries with high per capita GDP tend to have higher per capita road transport energy consumption. Per capita road transport energy consumption also varies due to factors such as relative resource abundance, vehicle ownership levels, consumption habits, and infrastructure (Liu et al., 2006).

As might be expected, four-wheeled motor vehicle ownership levels are closely associated with per capita road transport energy consumption. Figure 6 shows the relationship between ownership of these vehicles per thousand people and per capita road transport energy consumption in 84 countries in 2008. The size of the bubbles reflects total vehicle ownership in each country. Naturally enough, higher vehicle ownership levels are associated with higher per capita road transport energy consumption. In 2010, four-wheeled motor vehicle ownership per thousand people exceeded 600 in Canada, France, Italy, and Japan: in the US, it exceeded 800. In contrast, four-wheeled motor vehicle ownership per thousand people is much lower in developing countries (e.g. China and India: 37 and 17, respectively).

Figure 6 Four-wheeled motor vehicle ownership per thousand people versus per capita road transport energy consumption in 2008



Note: The area of each bubble is proportional to total vehicle ownership.

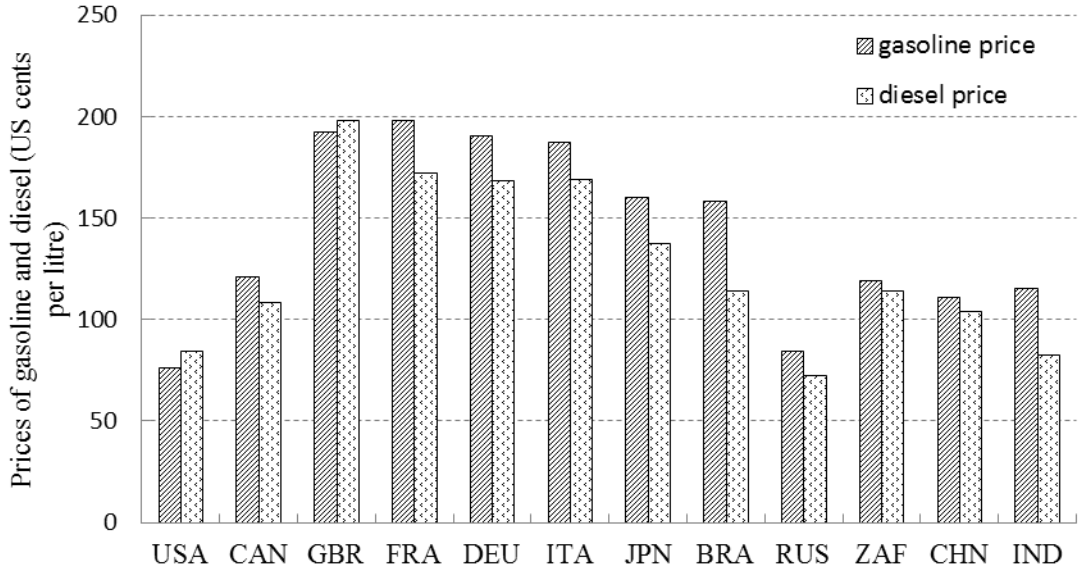
The number of high energy-consuming vehicles, such as sports utility vehicles, light vans, and light trucks, saw rapid growth in the US. This is a key reason why the per capita road transport energy consumption of the US was higher than in other countries (Du et al., 2013). A recent documentation of how vehicle ownership evolves as economies develop is provided by Nishitateno and Burke (2014).

Resource endowments also appear to influence per capita road transport energy consumption. The US and Canada are rich in fossil fuel resources: by the end of 2010, their proven crude oil reserves were 2.5 and 28.2 billion tonnes, respectively. Perhaps partly because of their relatively abundant energy supplies, among other reasons, the US and Canada have lower fuel

tax rates, meaning their fuel prices are relatively low and their consumption high (Burke and Nishitateno, 2013). France, Germany, and Italy are lacking in fossil fuel resources: by the end of 2010, their proven crude oil reserves were 10 million, 40 million, and 60 million tonnes respectively. Fossil fuel reserves are extremely deficient in Japan, with proven crude oil reserves of only 6 million tonnes in 2010. These resource-limited countries have had higher fuel taxes and implementation of energy-saving measures.

As shown in Figure 7, European and Japanese fuel prices are much higher than those in the US and Canada. The price differences arise mostly from the different fuel taxes collected by their governments (as well as international transport costs). The high fuel taxes in European countries and Japan reduce road transport energy consumption to some extent (Sterner, 2007; Burke and Nishitateno, 2013). These countries have also adopted policies to promote the development of public transport and encourage the use of fuel-efficient and/or clean-energy vehicles in an attempt to improve energy efficiency and reduce the demand for energy (Wei et al., 2010).

Figure 7 Gasoline and diesel prices in 2010



4 Structural changes in road transport energy

4.1 Oil is still dominant, but less so

Since 1973, the oil share of road transport energy has gradually reduced. In 1973, the oil share of road transport energy consumption exceeded 99% in the 12 countries we are studying. By 2010 this share had reduced in most countries, although Japan and South Africa had shown little change. In Brazil, the oil share of road transport energy consumption was only 75% in 2010. The fall in this share was mostly as a result of policies to encourage the substitution of oil with biomass energy: by 2010, Brazil's biomass energy share in road transport reached 22%. Biomass energy utilisation also increased rapidly in France, Italy, and the US, to 5.9%, 4.1%, and 4.7% respectively. Use of natural gas also increased, with the natural gas utilisation ratios of China and India rising from zero in 1973 to 4.7% in 2010.

Given the pressures on the environment and on fossil fuel resources in general, the proportion of clean energy in final energy consumption will likely increase in the future (Liao and Wei, 2010). With regard to road transport, a number of countries have adopted policies that

promote the uptake of clean energy, such as fuel taxes, subsidies for biomass, fuel economy standards, and tax incentives to purchase electric cars. As a result of these policies, pressure from rising oil prices, and ongoing technical progress, the vehicle fuel efficiency ratings of new vehicles have generally been improving in all countries (Cuenot and Körner, 2013).

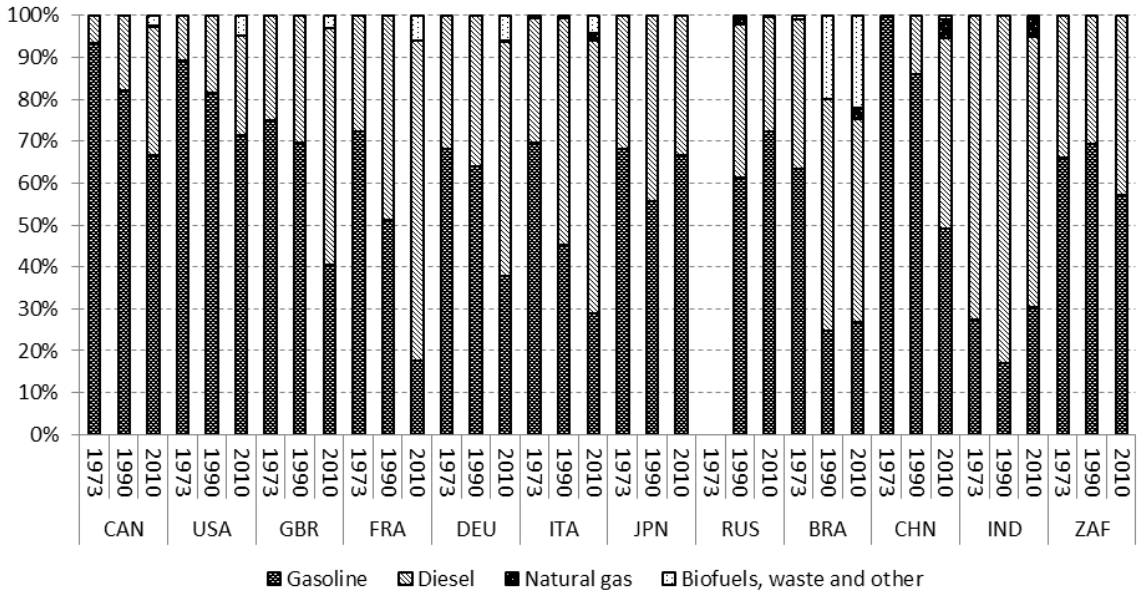
Electrically-powered vehicles continue to account for only a small share of the market: in 2012, hybrid electric vehicles only made up 1.5% of new-vehicle sales (IEA, 2013). This may well change over the next decade or two. Currently, however, gasoline and diesel generally remain cheaper road transport options than the alternatives. While alternative technologies are improving quickly, ongoing improvements in the fuel economy of gasoline- and diesel-powered vehicles make the task of achieving mass sales of alternative technologies (e.g. electric vehicles) more challenging.

Most affordable models of electric vehicles still do not run far without being recharged, although advances are ongoing. There is a need for a roll-out of more charging facilities to see broader uptake. Given the challenges associated with alternative energy sources, oil will likely keep its dominant position in most countries in the medium term. In the long term, however, pollution concerns and resource constraints mean it is likely that alternative technologies such as electric vehicles will come to dominate the market. If their costs continue to decrease, in the long run a mass transition to non-oil powered vehicles appears inevitable.

4.2 The rise of diesel

The main oil products used in road transport are gasoline and diesel. As shown in Figure 8, the relative importance of diesel and gasoline varies. The proportion of diesel consumption increased in all the countries due to the increasing popularity of diesel vehicles given their higher energy efficiency. Some countries, particularly in Europe, have had policies to encourage the use of diesel vehicles (Wallington et al., 2013).

Figure 8 Energy sources used in road transport



In 1973, gasoline consumption in the road sector exceeded diesel consumption, except in India. By 2010 the proportion of diesel consumption had increased (except in India). In the UK, France, Germany, and Italy, diesel is now the main road transport fuel. From 1973 to 2010, China's use of diesel for road transport has increased significantly due to rapid growth in freight transport. Gasoline and diesel now rank as equally important as fuel sources for road transport in China.

4 Conclusions

Transport is a key energy consuming sector, and road transport is the major part thereof. With continued increases in income levels, the shares of transport energy in total final energy consumption and of the road transport sector in transport energy consumption will likely continue to increase for some years to come. In the long run, fuel-efficient vehicle technology might place the brakes on this rise, although energy efficiency improvements are likely to occur in other sectors also.

The per capita road transport energy consumptions of different countries vary widely, with the US and Canada far exceeding the other developed countries we have examined. In addition to economic development, per capita road transport energy consumption is also affected by factors such as fuel tax policies, the abundance of resources, and residential consumption habits (e.g. vehicle ownership decisions). For a variety of reasons, road transport energy consumption growth is in a decelerating phase in developed countries. It is far from clear that these countries are near “peak energy use in the road transport sector”, however.

Oil has been the main source of road transport energy consumption. This situation may persist in the medium term, despite advances in alternative technologies such as electric cars. The market share of clean, renewable energies remains small, but they are likely to play a larger role in the future. The proportion of diesel consumption is increasing.

As a rapidly developing country, China’s road sector has been expanding quickly due to urbanisation, infrastructural improvement, and increasing personal incomes. Oil will likely be

China’s main source of road transport energy consumption for some years to come, although pollution and resource considerations suggest that it would be best for China to not follow the transport development paths of the US or Canada. Fortunately energy efficiency is improving, and there are numerous policy options available for reducing negative externalities from the road transport sector. These include externality pricing of emissions and congestion, public transport initiatives, and vehicle energy efficiency initiatives.

Acknowledgements

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